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The Drama of Fishing Commons: Cournot-Nash Model and Cooperation

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The interdisciplinary research related to common resources has become extremely important, because commons are a very complex theme and in fact they need the contribution of several areas of knowledge.

Commons have long been a central theme in the environmental problems, such as the global environmental changes or overfishing. "Tragedy of the Commons" (Hardin, 1968) is a reference in this area. There are also many comedies on commons, as well (see, for example, Dietz *et al*, 2002). These authors explain why sometimes there are dramas on commons (not just tragedies but also comedies). Agrawal (2002) presents some conditions to a sustainable management on commons, as well.

In order to find out solutions to the problem of resources, cooperation has been seen as an interesting way to reach good results in commons exploitation area. We'll show how cooperation, in general, is important to avoid tragedies and how it may contribute to implement conservative practices.

In the international cooperation field or in the processes of decision making the institutions which deal with these matters got very important. Cooperation on institutions that manage the commons can be observed in Richerson *et al*, 2002.

Studies about cooperation on fishing area were made, for example, by Gronbaek (2000), who studies a cooperative and a non-cooperative solution in fishing field and formalizes mathematically a sustainable cooperative solution. Munro (2002) presents some interesting cases of cooperation on fishing area. Miller and Munro (2002) shows that cooperation, in general, is important and that non-cooperative fisheries normally lead to the overexploitation of the resources.

We'll study the effects of cooperation between two Portuguese fishing producers' organizations (POs). Names of POs will be omitted to keep the confidentiality of these organizations. We'll express their relationship with national fishing Portuguese authorities, as well.

Our model gives a view of benefits of cooperation to the members of this kind of organizations and gives a view of the advantages of cooperation for the conservation of Portuguese sardine stocks, which are included in those stocks that we call Ibero-Atlantic stocks. Generally, this allows us to analyze the effects of cooperation on the study of the problem known as the "Drama of the Commons".

Cournot-Nash Model

General Remarks

We aim to study sardine fisheries by using economic theory of Cournot oligopoly and by using Nash equilibrium, combining both approaches.

Levhari and Mirman (1980) have presented an example using a dynamic Cournot-Nash solution for fish wars and it has become a reference for fishing games.

We have considered an original variable for this kind of models (fishing effort), in order to study the efficiency of the inputs used in sardine fisheries in Portuguese waters.

In fact, our Cournot model and the consequent Cournot-Nash equilibrium will allow us to analyze the contribution of cooperation for the preservation of sardine in Portuguese waters and it will allow us to analyze its contribution for the stabilization of fishers' rents.

The Basic Model

The usual model (an oligopoly model) allows us to determine simultaneously the quantities produced by a few number of companies. Our model intends to study two POs, which members produce a homogeneous product (sardine). Sardine catches are the quantities (q) used in the traditional Cournot model.

When we consider two POs, producing sardine (considered here as a homogeneous product) and selling it in the same market, they will try to maximize their own profits (their own rewards in the game). This profit is given by the difference between sales and costs. Each one reward function (or profit function) is given by:

$$\pi_1(q_1, q_2) = RT_1 - CT_1 \tag{1}$$

$$\pi_2(q_1, q_2) = RT_2 - CT_2 \tag{2}$$

In these equations πi, RT_i and CT_i are respectively profit, total sales and total cost for PO_i and i = 1, 2. Sales function of each one of both POs results from applying a price to the quantity sold by a PO and it is given by:

$$RT_1 = p(q) * q_1 = [A - b(q_1 + q_2)] * q_1 = Aq_1 - bq_1^2 - bq_1q_2 \tag{3}$$

$$RT_2 = p(q) * q_2 = [A - b(q_1 + q_2)] * q_2 = Aq_2 - bq_1q_2 - bq_2^2 \tag{4}$$

and p(q) is the market price as a function of quantities q. The quantity q is the total quantity produced and sold in the market (i.e., $q = q_1 + q_2$). A and b are constant values and q_1 e q_2 are the quantities produced and sold respectively by PO_1 and by PO_2.

POs costs are

$$CT_1 = cq_1 \tag{5}$$

$$CT_2 = cq_2 \tag{6}$$

and c is a constant (c>0). We consider here that both POs have the same costs (and consequently c has the same value for both POs). However, this proceeding is not a necessary requirement for the analysis.

$$\pi_1 = Aq_1 - bq_1^2 - bq_1 q_2 - cq_1 \tag{7}$$

and

$$\pi_2 = Aq_2 - bq_1 q_2 - bq_2^2 - cq_2 \tag{8}$$

Equations 7 and 8 allow us to maximize profits. We can do so through the following equations:

$$\frac{\partial \pi_1}{\partial q_1} = A - 2bq_1 - bq_2 - c = 0 \tag{9}$$

$$\frac{\partial \pi_2}{\partial q_2} = A - bq_1 - 2bq_2 - c = 0 \tag{10}$$

From equations 9 and 10 we must have q_1 e q_2 such as

$$q_1 = \frac{A - bq_2^e - c}{2b} = f(q_2) \tag{11}$$

and

$$q_2 = \frac{A - bq_1^e - c}{2b} = f(q_1) \tag{12}$$

and q_i^e represents the quantity produced by PO_i, which is its expected production.

Those are the quantities that allow us to maximize the profit for each one of both POs, given the expected production for each other's competitor in the market. As this is a simultaneous game, each PO makes its own decision about production but it does not know which will be the decision of its competitor in the market. In each one's process of decision, each PO will just use the expected value for the production of its competitor in the market. The equations 11 and 12 will be precisely the reaction functions for PO_1 and PO_2. Each one will choose the quantity that maximizes its own profits (given the expected production for its competitor). In fact, the quantity that PO_i will produce will correspond to the best reaction that this PO expects will be the choice made by its competitor.

A Nash equilibrium is a solution in which the players strategies represent the best answers one to each other, reciprocally. So, in this model, $q_1 = q_1^e$ and $q_2 = q_2^e$. This means that the quantity that PO_1 has produced represents the quantity that PO_2 expected PO_1 would produce. This is the strategy followed by PO_1. The same procedure happens for its competitor PO_2. So, we'll have:

$$q_1^* = \frac{A-c}{3b} \tag{13}$$

and

$$q_2^* = \frac{A-c}{3b} \tag{14}$$

So, q_1^* and q_2^* are the values that represent the Nash equilibrium. In this solution, no PO has any incentives to change its own solution, because these ones are the best strategies, each one for each PO. Both POs follow their best strategies that correspond to the best responses to the strategy followed by its competitor in the market. This is the Cournot-Nash equilibrium for both POs.

For more than two POs, we can use the same philosophy for the analysis. If there is a large number of POs, Cournot model represent a competitive model where we have n homogeneous products and n POs in the market. We'll have the following relationships:

$$RT_i = p(q) * q_i = Aq_i - bq_i^2 - q_i b \sum_{j \neq i}^{n} q_j \tag{15}$$

and p(q) is given by $p(q) = A - b\sum_{1}^{n} q_i$ (we can see that $\sum_{1}^{n} q_i$ represents the total production for all POs that depends on market price) and $\sum_{j \neq i}^{n} q_j$ represents the sum of production for all POs, excluding PO_i. Given the usual hypothesis that $C_i = cq_i$, we'll have:

$$\pi_i = Aq_i - bq_i^2 - q_i b\sum_{j \neq i}^{n} q_j - cq_i \tag{16}$$

and

$$\frac{\partial \pi_i}{\partial q_i} = A - 2bq_i - b\sum_{j \neq i}^{n} q_j - c \tag{17}$$

As products are homogeneous and marginal costs of each one of all POs are the same and equal to c, we'll have the same share of the market for each one of all POs. All of them produce the same quantity. As a result, we'll have $q_i = q_j$ for all j and $\sum_{j \neq i}^{n} q_j = (n-1) * q_i$, because each one of all POs produce the same quantity. So we have now:

$$\frac{\partial \pi_i}{\partial q_i} = A - 2bq_i - b(n-1)q_i - c = 0 \tag{18}$$

or yet

$$\frac{\partial \pi_i}{\partial q_i} = A - b(n+1)q_i - c = 0 \tag{19}$$

and so,

$$q_i^* = \frac{A - c}{b(n+1)} \tag{20}$$

This is the same result we got for two POs (n=2). Besides, total quantity is given by

$$q = nq_i^* = \frac{n(A-c)}{b(n+1)} = \left[\frac{A-c}{b}\right]\left[\frac{n}{n+1}\right] \tag{21}$$

If n comes close to infinity, this last expression comes close to 1. This means that when there are a large number of POs in the market, we'll have $q = \frac{A-c}{b}$. We also know that in a competitive market, each PO will produce until the market price comes to the level of marginal cost. This fact explains the reasons why we have similar results through the Cournot model and through a model of a complete competitive market.

If there is cooperation between POs (n = 2), we'll have a collusion solution. Now, we'll have the sum of both profit functions to get the total profit for the collusion. So, we have now:

$$\pi_T = \pi_1 + \pi_2 \tag{22}$$

Our aim is to maximize the aggregate profit:

$$\begin{aligned} \frac{\partial \pi_T}{\partial q_1} &= 0 \\ \frac{\partial \pi_T}{\partial q_2} &= 0 \end{aligned} \tag{23}$$

We'll have now a solution for POs collusion. The optimal quantities result from both POs collusion. These quantities will assure major profits for the collusion. The consequent results will show that the final global profit is expected to be better than the old situation and one PO or both may improve their own situation. This means that, in an extreme situation, one PO may rest in a worse situation, although the global situation is always better than the solution without cooperation. So, sometimes it is possible to negotiate and to agree side payments to transfer benefits to the agents (if any) which situation got worse than before. Besides, we can expect that prices will increase and quantities will decrease under cooperation.

The New Model

Cournot model is a model of quantities. In the usual fishing theories, there is a variable representing quantities that has a formal relationship with fishing effort. In fact, there is an obvious relationship between fishing effort and catches of fish. Catches represent the production of fish (q). In our model, we replace this variable (quantities) by another variable, related to that one, what represents precisely the fishing effort (E). Our aim is to analyze if there is a direct relationship between fishing effort and cooperation, in order to study if lower levels for fishing effort induce more conservative politics for species, more sustainable resources and better rents for fishers in the long term, as well. So, the usual equations

$$\pi_i(q_1, q_2) = RT_i - CT_i \tag{24}$$

(i = 1, 2) are replaced in the model by the equations

$$\pi_i(E_1, E_2) = RT_i - CT_i \tag{25}$$

(i = 1, 2). We have q_i as a function of E_i and X. In fact, q_i = f (E_i,X) and represents the produced quantity (i.e, catches), E_i is the fishing effort used by PO_i, X is the biomass level for sardine and πi, RT_i and CT_i are respectively profit, total sales and total cost for PO_i, as before. We'll have now the following functions for sales:

$$RT_1 = p(q) * q_1(E) = \left[A - b(q_1 + q_2)\right] * q_1 = \left[A - b(f(E_1, X) + f(E_2, X))\right] f(E_1, X) \tag{26}$$

$$RT_1 = Af(E_1, X) - bf(E_1, X)^2 - bf(E_1, X) f(E_2, X) \tag{27}$$

and

$$RT_2 = p(q) * q_2(E) = \left[A - b(f(E_1, X) + f(E_2, X))\right] f(E_2, X) \tag{28}$$

$$RT_2 = Af(E_2, X) - bf(E_1, X) f(E_2, X) - bf(E_2, X)^2 \tag{29}$$

Besides, PO costs are given by $CT_1 = cE_1$ and $CT_2 = cE_2$, in which c is a constant (c>0). We consider, as before, the same costs (c) for each PO. As we have already seen, this proceeding is not a necessary requirement for the analysis.

Now, we'll formalize the model in order to solve the mathematical problem through the following equations:

$$\frac{\partial \pi_1}{\partial E_1} = 0 \tag{30}$$

and

$$\frac{\partial \pi_2}{\partial E_2} = 0 \tag{31}$$

Now, we'll get the optimal values for E_1 and E_2. Additionally, $E_i = E_i^e$ represents the level for fishing effort expected by PO_j for PO_i ($i \neq j$, i, j = 1, 2). The solution E_i^* (i = 1, 2) represents the optimal fishing effort for PO_i. These levels will maximize individual rents for POs, in a competition basis and represent the optimal levels for fishing effort, those that maximize rents for each PO, knowing previously the expected level for its competitor's fishing effort in the market. As this is a simultaneous game, each PO makes its own decision about its fishing effort that it will apply to the fishery, but it does not know the decision that is made by its rival in the market. So, each company just considers the expected level of fishing effort for its competitor in the market. Consequently, we'll know the reaction functions for each PO and, as it was already seen, we will determine the fishing effort level that maximizes rents for each PO, given the expected fishing effort for its competitor. The decision of each PO about its fishing effort level represents the best response to the decision made by its competitor in the market. Such a decision, made by one PO, represents the decision its competitor would expect this PO would make about fishing effort. Consequently, without cooperation, the solution for the problem is a Nash equilibrium solution and it is the best solution E_i^*. In this level for fishing effort, no PO has any advantages to change its own strategy in the game because this is the best level of fishing effort and it represents its best strategy.

Now, we'll consider that both POs cooperate and that they make arrangements in order to get benefits from the collusion between them. Now, both POs will maximize aggregate rents, instead maximizing their own rents, individually. That is the goal. In order to see this, consider now

$$\pi_T = \pi_1 + \pi_2 \tag{32}$$

To maximize the aggregate profit we'll have a solution (the collusion solution) from the resolution of the following:

$$\begin{aligned} \frac{\partial \pi_T}{\partial E_1} &= 0 \\ \frac{\partial \pi_T}{\partial E_2} &= 0 \end{aligned} \tag{33}$$

In the solution for this problem, aggregate fishing effort is expected to reach a lower level than the sum of the reached levels for each individual solution. This is consistent with benefits expected for the members of POs, because costs of fishing are expected to be lower. As an additional result, it is expected that the market price would be higher and the aggregate rent would be higher, as well. Besides, as the aggregate fishing effort is expected to be lower, we can expect that fishers will control catches of fish as well, and consequently, we'll expect to get a stock's management more compatible with conservative objectives.

In practice, we have analyzed two POs in Portugal, representative in sardine Portuguese market, which members are competing in the same market and producing a homogeneous product (sardine). In short, both POs exploit Portuguese Sardine Stock and they sell it in the local market.

The geographical limits for Sardina Pilchardus Walbaum in which Portuguese Sardine is included are, in the North, the frontier between France and Spain and, in the South, Gibraltar. This area corresponds to the VIIIc and IXa divisions of ICES (see annexed figure 1).

Biological factors for sardine abundance

The abundance of sardine rests very dependent of sardine recruits entering on fishing biomass. Analyzing the period since the middle of 1990s, we can note that years 2000 and 2001 had very strong recruitment processes, particularly the first one of these years, due to several factors (biologic, fishing effort and others) - see annexed figure 2. Besides, analyzing stock spawning biomass (SSB), we can see that there were very good levels for SSB in the last years of the series. SSB grew up since 2000 until 2003 and high levels for SSB have been maintained since then - see annexed figure 3. It seems that there has been a good reproduction capacity for this specie and there has been a good evolution for sardine Portuguese stocks - see annexed figure 4, as well.

The Importance of Agents Cooperation for Sardine Stocks and Fishers' Rents

Due to the existing agreements between the two POs and between POs and authorities, sardine mortality (figure 5) through fishing has been decreasing since 1998.

In addition POs have promoted some measures to reduce catches and to organize markets, preserving species for the future generations and protecting fishing present interests. POs have well controlled the activity of fishers and controlled catches. Catches levels have decreased and fishers' rents have benefited from good POs management practice and from the existing cooperation between POs (but also from the cooperation between POs and fishing authorities).

Sardine prices have sustainably increased (Figure 6) and catches were already kept in high levels (figure 7). However POs implemented important measures to reduce fishing effort. These facts have been reflected in the fishers' high rents levels.

Results

General Considerations

The conclusions of our model seem to be well understood by all stakeholders of fishing sector and, consequently, communication between all the agents seems to become easier.

Many factors for cooperation have been required and consequently they have been promoted. Therefore, the relationship between local POs and national DGPA (national authority that rules the fishing sector) has become more profitable and good results got evident.

Thus, programs of exploitation of Portuguese sardine have had interesting results and brought a sustainable rents policy for all the sector's agents, since they are involved and since they approve the rules proposed for a cooperation policy in fisheries.

As we can see, cooperation promote a reduction in catches but prices are kept at high levels and rents are assured. In fact, this model shows that cooperation can be well understood by stakeholders of fishing sector and it proves that there are great benefits, through just a simple way of managing fisheries. Theory of games has become important to analyze the way how natural resources are exploited and allows an integrated but simple model to analyze the decision making process on politics fishing area and, particularly, on fishing practices.

Conclusion

Cournot-Nash model contributes to see that cooperation is important to the preservation of species and to the preservation of fishers' rents in the long term and to the socio-economic stability of coastal communities.

Our study also permits to conclude that there is a good management of sardine stocks in Portuguese waters and that there is a sustainable exploitation for this resource in the long term.

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Figure 1

ICES VIIIc and IXa Delimited Divisions (Source: IPIMAR)

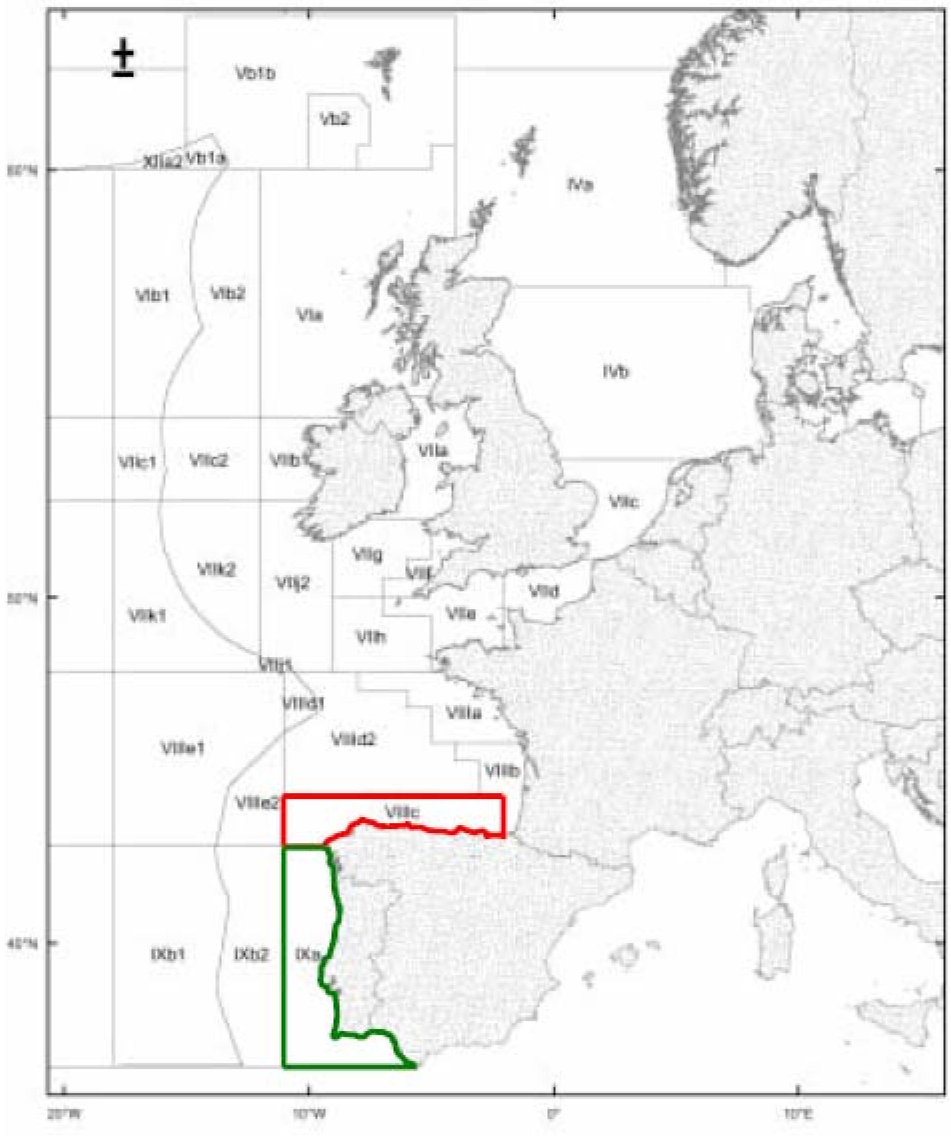


Figure 2
Sardine Recruitment, in Billions of Recruits (age 0), in ICES VIIIc and IXa Divisions. Source: IPIMAR.

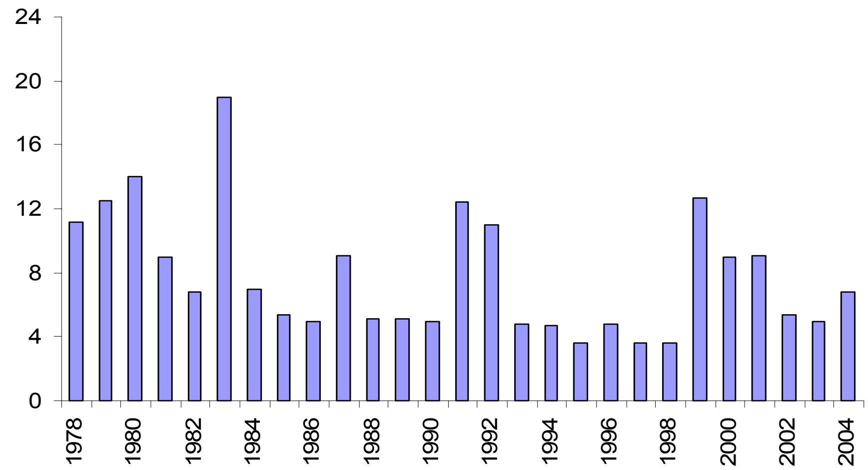


Figure 3
Sardine Stock Spawning Biomass (SSB), in Thousands Tons, in ICES VIIIc and IXa Divisions. Source: IPIMAR.

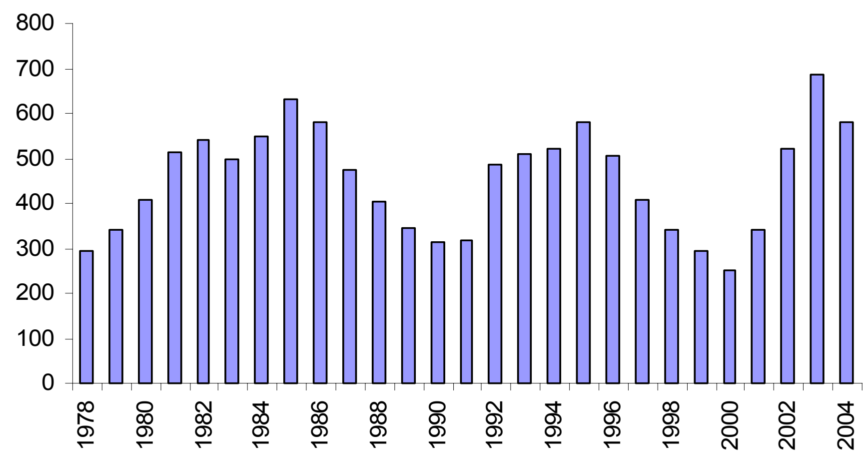


Figure 4
Sardine Biomass in Portuguese Waters,
in Thousands Tons (IPIMAR Campaigns).
Source: IPIMAR.

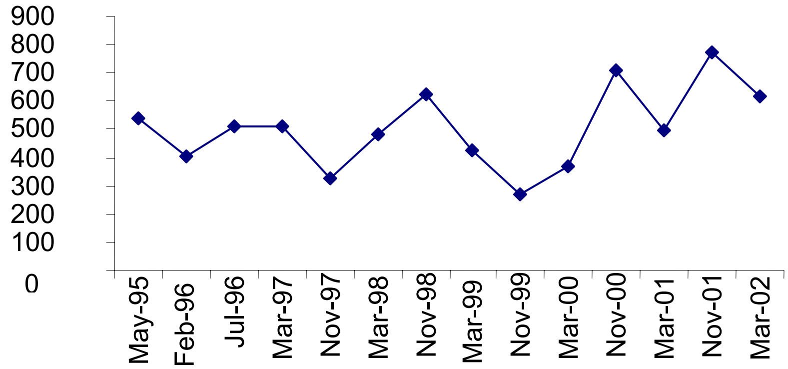


Figure 5
Sardine Fishing Mortality (F), in ICES VIIIc and IXa Divisions.
Source: IPIMAR.

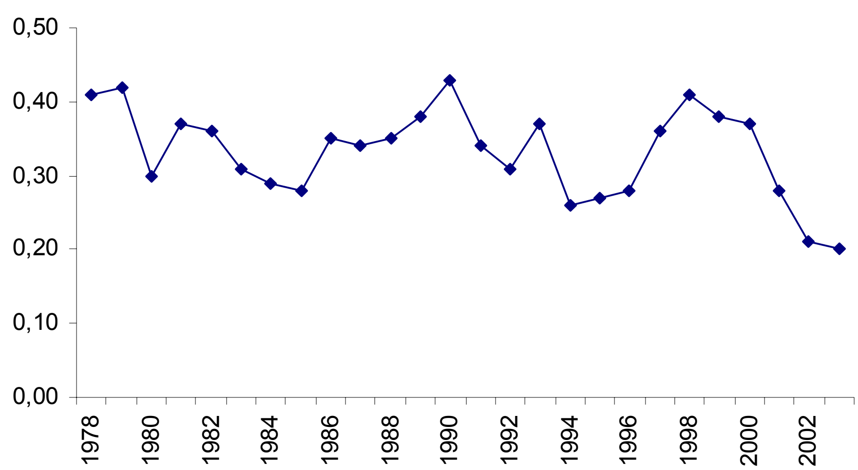


Figure 6
PO_1 and PO_2 Prices for Sardine (euro/Kg). Source: DGPA.

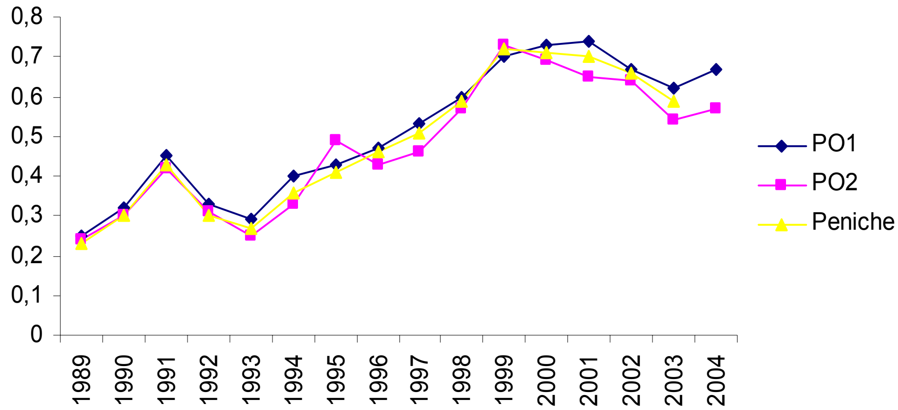
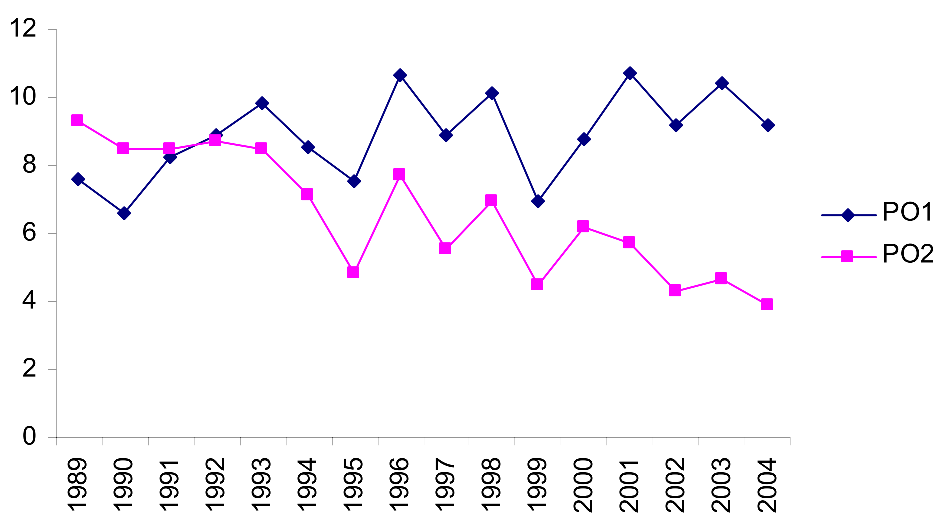


Figure 7
PO_1 and PO_2 Catches of Sardine (Thousand Tons).
Source: DGPA.



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